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# DESIGN AND OPERATION OF THE RHIC 80 K COOLER

A. Nicoletti, A. Reuter, A. Sidi-Yekhlef, P. Talty, E. Quimby

Cryogenic Engineering Group
Collider-Accelerator Department
Brookhaven National Laboratory
Upton, New York 11973

## ABSTRACT

A stand alone cryogenic system designed to maintain the magnets of the Relativistic Heavy Ion Collider (RHIC) at between 80 and 100 K during accelerator shutdown periods has been conceived and designed at Brookhaven National Laboratory and built by PHPK Technologies of Columbus, Ohio. Since most thermal contraction occurs above this temperature, this unit, referred to as the 80 K Cooler, will eliminate the stresses associated with thermal cycling. The cooling system will provide the necessary refrigeration by circulating cooled Helium gas at approximately 15 atmospheres through the RHIC heat shields and magnets. This Helium is cooled by heat exchange with liquid nitrogen and circulated via three cold centrifugal pumps. The nominal delivered cooling capacity required to maintain the magnets at temperature is approximately 36 kW, primarily intercepted at the heat shield. The system also has separate heat exchangers for use as a pre-Cooler from room temperature to 82 K. Selection of sextant or sextants for pre-cooling is designed into the RHIC cryogenic distribution system. Topics covered include Cooler design decisions, details of the Cooler as built, integration into the existing RHIC cryogenic system and initial operating experience.

## RHIC CRYOGENIC SYSTEM

During normal operation, the Relativistic Heavy Ion Collider is cooled by the main 24.5 kW refrigerator[1]. Six beam crossing regions divide each ring of the accelerator into sextants, which can individually be warmed up and cooled down while the rest of the machine is maintained at operating temperature[2]. Connections from the main refrigerator to the rings are made in cryogenic cold boxes located at the six o'clock crossing region. These are the 4.5 K magnet cooling supply and return connections, a heat shield supply and return which typically operate between 40 and 70 K and an auxiliary line used during full ring or single sextant cool down.

RHIC was not intended to operate year round. Laboratory power consumption restrictions have, and will continue to, limit the duration of the experimental physics program, with the average run to date lasting about 28 weeks. Since its commissioning in 1999, RHIC has undergone four full cool down /warm-up cycles, and has been subject to the thermal stresses associated with this temperature cycling. A cryogenic cold box, designed to eliminate this wear by maintaining the accelerator below 100K while the main refrigerator is not running, was constructed during the winter of 2002 by PHPK Technologies of Columbus, Ohio and installed at BNL in Spring 2003. This system, referred to as the 80K Cooler, was intended to be independent of the main refrigerator, so required refrigerator maintenance and upgrades planned over then next several shutdown could be completed. It's cooling is purely Nitrogen based in order to take advantage of the relative cost of liquid Nitrogen as compared to electrical costs of running compression based Helium refrigeration. The Cooler was brought on line as part of the RHIC warm up in late May, 2003. It is shown arriving at BNL in figure 1.

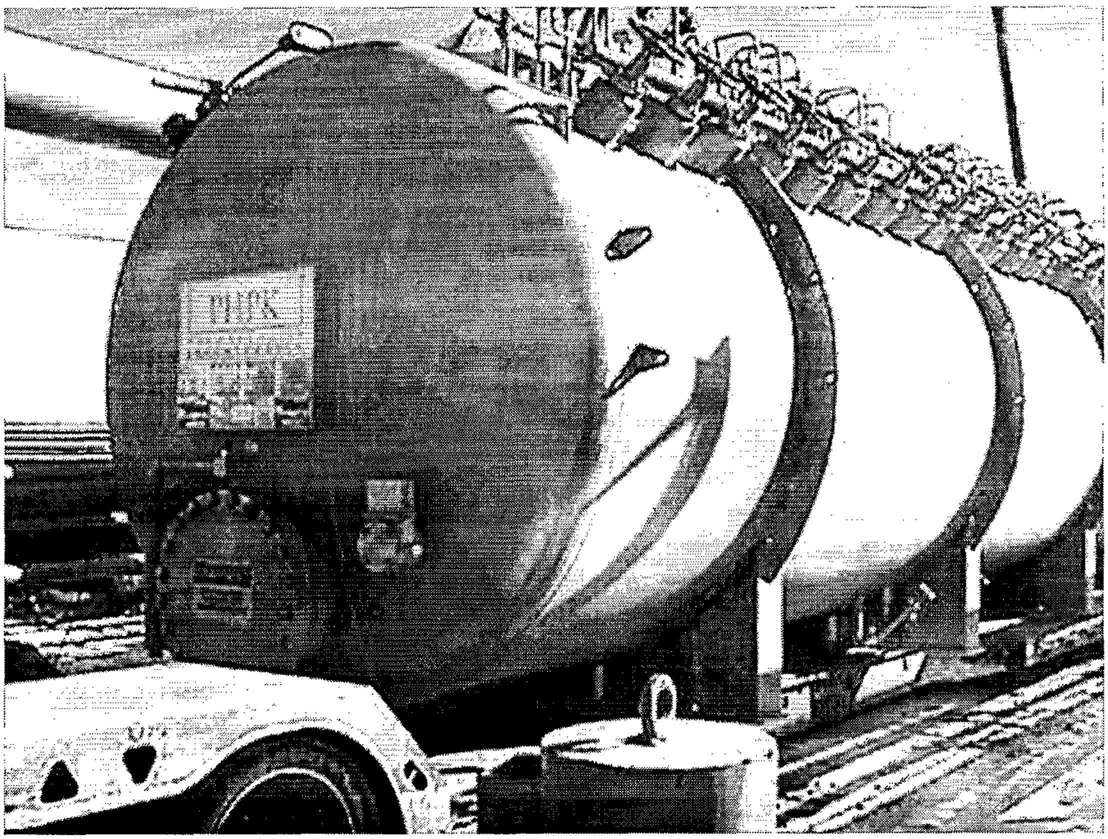

Figure 1. 80K Cooler cold box as it arrives at Brookhaven National Laboratory

## COOLER DESIGN

The Cooler's primary mode of operation is maintaining the accelerator between 80 and 100K however, when supplied with high pressure Helium, it also has the capability of cooling magnet from room temperature down to 80K. These functions can be performed independently and simultaneously, that is, the Cooler can maintain and cool different sextants at the same time. The maintenance loop consists of one plate/fin heat exchanger, HX1 in the process and instrumentation drawing for the Cooler shown in figure 2, three boiling liquid Nitrogen tube and shell heat exchangers, HX's 2,3, and 4, and three cold circulating pumps in series, each about 28 hp. Heat exchangers one and two are designed to remove the ring heat load, an anticipated 36 kW, while heat exchangers three and four primarily remove the heat of compression from the circulators, expected to be about 40 kW total.

The Cooler is designed to deliver a nominal 300 g/s of Helium at 80 K and 14.5 atmospheres to the rings. This supply pressure is based in ring pressure drop and pump sizing considerations. The cold supply transfer line from the Cooler branches off to connect to the magnet and heat shield lines in each ring through cold box penetrations at the ring 6 o 'clock crossing region. Control valves in the transfer lines split the flow with an anticipated 125 g/s flowing through each heat shield and 25 g/s through each magnet string. This flow is split unevenly because the expected majority of the heat flux into the system is being intercepted at the heat shield. The Helium flows around the rings and returns to the Cooler again via connections at the 6 o'clock valve box at design process conditions of 10 atmospheres and 105 K.

In cool-down mode, the Cooler is designed to receives 200 g/s of room temperature Helium at 16 atm which it cools to 80K via one plate fin heat exchanger and a pool boiling liquid Nitrogen heat exchanger, HX's 5 an 6 respectively. The Cooler is designed to cool a ring down in less than one week if supplied the maximum flow rate. A bypass was installed around HX 5 to minimize the temperature gradient across that heat exchanger when first beginning the cool down process. The outlet for this cold, high pressure gas is again connected to each ring of the accelerator through the 6 o'clock cold boxes. Once inside the ring the Helium can be directed to the sextants to be cooled via the existing cryogenic distribution system.

Other design features of the Cooler include:

- The ability to isolate, bypass, warm up and remove any of the circulating compressors while maintaining operations on the other two.
- The ability to isolate, bypass warm up and regenerate any of the heat exchangers, with the maintenance portion of the Cooler still operating.
- Enough liquid Nitrogen storage capacity in the pool boiling heat exchangers to sustain maintenance cooling loop design parameters after one hour without a Nitrogen fill.
- A heater for warming and regenerating heat exchangers.
- A glycol based coolant circulating system mounted on the side of the cryostat designed to temperature stabilize the motors on the three cold Helium pumps.

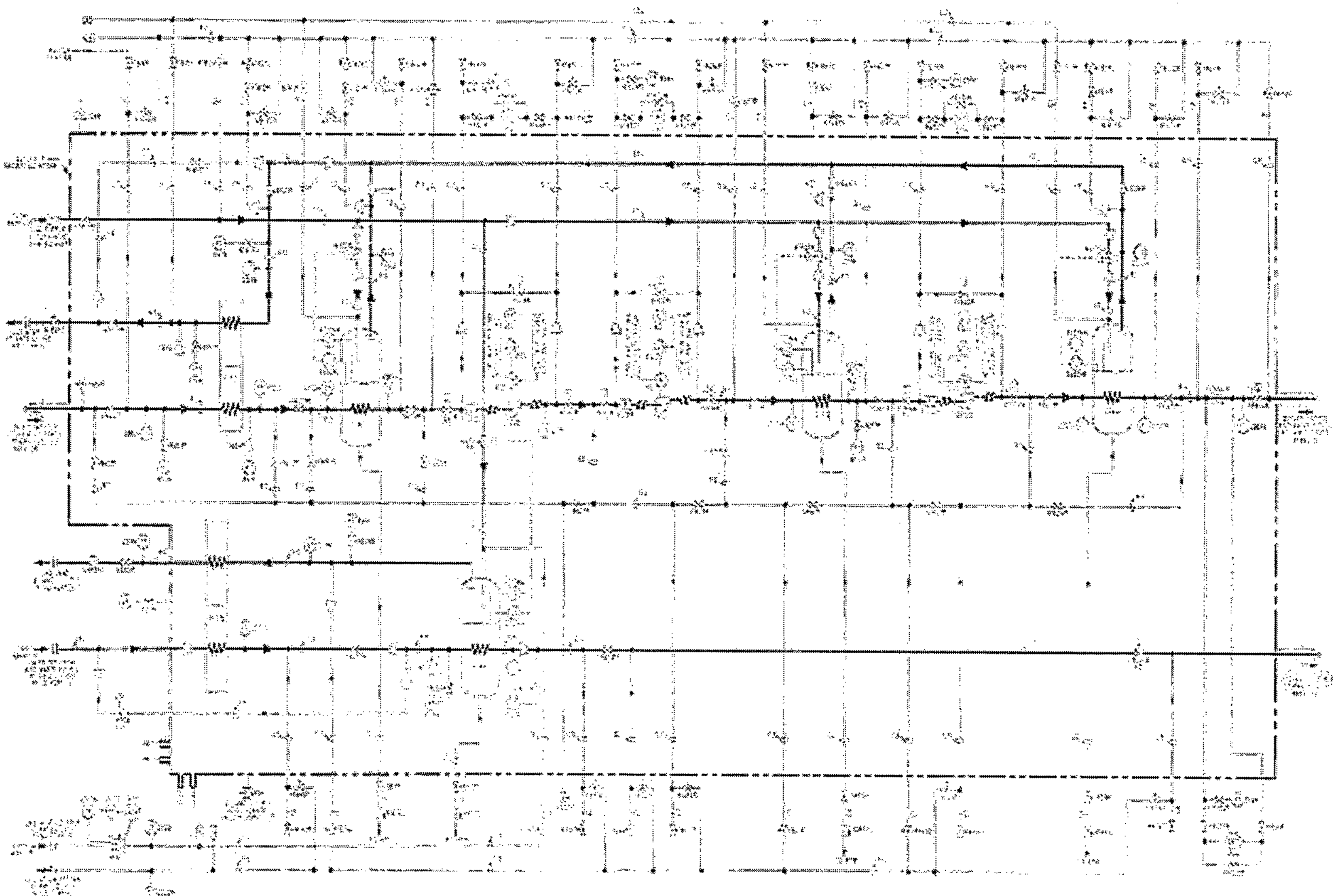

Figure 2: 80K Cooler Process and Instrumentation Drawing

## INTEGRATION

Of primary importance in integrating the Cooler into the RHIC cryogenic system was to insure it could operate in maintenance mode while still permitting work to be completed on the main refrigerator and compressors. Cooler penetrations into the ring Helium distribution system were chosen so that existing cold box valves isolated high pressure Helium in the Cooler circuit from any connections in the 6 o'clock cold box that lead back to the refrigerator. Two warm connections, one used to charge the system and make up any Helium loss from leaks, the other to drain any excess pressure in the system, are connected to high pressure warm gas storage tanks, which can be isolated from the rest of the cryogenic system. Thus no other equipment need be running while the Cooler is in maintenance mode.

For cool down mode, the Cooler was connected to an existing process line that had supplied warm pressurized gas to the ring during magnet warm up. This pressurized, purified Helium can come from either the main refrigerator compressors, or a smaller utility compressor previously dedicated to system scrubbing. Existing warm piping routes the Helium back to the suction side of the compressors. Other connections to the Cooler are Nitrogen sources for the heat exchanger bath and regeneration system, both of which come from an existing 20,000 gallon liquid storage dewar positioned adjacent to the Cooler.

## OPERATIONAL EXPERIENCE

The end of RHIC 02/03 experimental run saw the need for repairs at several locations in the accelerator. One repair, which required the removal of a magnet for the duration of the shutdown, necessitated one sextant be warmed up to room temperature immediately following the physics program. Other repairs would have effectively precluded cooling large sections of the accelerator for several weeks. The decision was made to bring the Cooler on the available sextants for only two weeks in order to establish it could operate in a stable maintenance mode within expected design parameters, then warm all magnets to room temperature.

### Transition From 4.5 K

At the conclusion of the physics program, ring cooling using the main refrigerator was stopped, and the majority of the Helium inventory transferred to gas or liquid storage. The rings were warmed by magnet heaters to about 25K at 3 atmospheres, then isolated in order to contain any remaining Helium. Heaters continued to warm the magnets until expected operating conditions of the Cooler, 80K at 10 atm, were reached. The sextant containing the long-term repair magnet was isolated and warmed directly to room temperature. A Helium flow path for the Cooler was established around it using piping in adjacent beam crossing region cold boxes. This flow path presented some operational limitations, as it required crossover connections between the magnet and heat shield, cooling circuits in one of the rings. The two circuits were intended to operate completely in parallel. When the Cooler was brought online, it was on one ring as designed, but the only on five of six magnet sextants, and four of six heat shield sextants in the other.

Some problems were encountered on transitioning to the Cooler. Loss of insulating vacuum in several sextants and transfer lines on the initial magnet warm up from 4.5 K caused an uneven ring temperature profile so several bumps up to 115 K had to make their way out of the system. Also, the sections of the heat shield had warmed up to near 120K while the magnets were warming to 80K. Although the mass in the heat shield is significantly less than the magnets, these waves still represented heat that had to be removed by the Cooler. Keeping up with the Cooler's Nitrogen consumption rate in this period proved to be challenging, as heat removal from the ring approached 60 kW. In retrospect establishing the heat shield loop while still warming the magnets to 80K using the heaters, which is possible given the piping configuration, would have provided for a smoother transition. Still, the Cooler's ability to remove this additional heat demonstrates excess capacity in the heat exchanger design. Once these high temperatures had moved out of the system, the Cooler settled into steady state operational mode.

**Cooler Performance**

Bringing on line three cold circulators arranged in series, which was a concern at the design stage, did not prove to be an operational issue as speeds and flow rates ramped up in parallel quite smoothly. Once circulator speeds were set, and temperature peaks from the transition had moved out of the system, the Cooler was able to sustain the rings at design conditions with great stability and minimal operator intervention. A control screen display showing steady state mode is shown in figure three. Ring heat loads, and pressure drops, circulator pump speeds, heat exchanger performance, and Cooler Nitrogen consumption rates, about 10,000 gallons/day all fell reasonably within expected limits.

The Cooler ran in this mode for several days, then one of the Helium circulating pumps was shut off and bypassed. With the other two pumps increased to their maximum operating speed, the overall flow rate was only reduced by about 10 percent. In this mode, ring temperatures were slightly up, but Nitrogen consumption values were down and higher pump adiabatic efficiencies were seen at the higher speeds. This proved to be a viable alternate operating mode.

Finally, prior to ring warm-up, the system was left to run in maintenance mode with liquid Nitrogen supply valves shut, thus verifying the one of the Cooler's design criteria of maintaining operating conditions after one hour without a liquid Nitrogen supply.

**CONCLUSIONS AND FUTURE PLANS**

The 80K Cooler cryogenic cold box is able to maintain the RHIC accelerator at the Cooler's design conditions and will eliminate the stresses associated with thermal cycling the magnets every shutdown. It will be a part of cryogenic operations in the future. As of

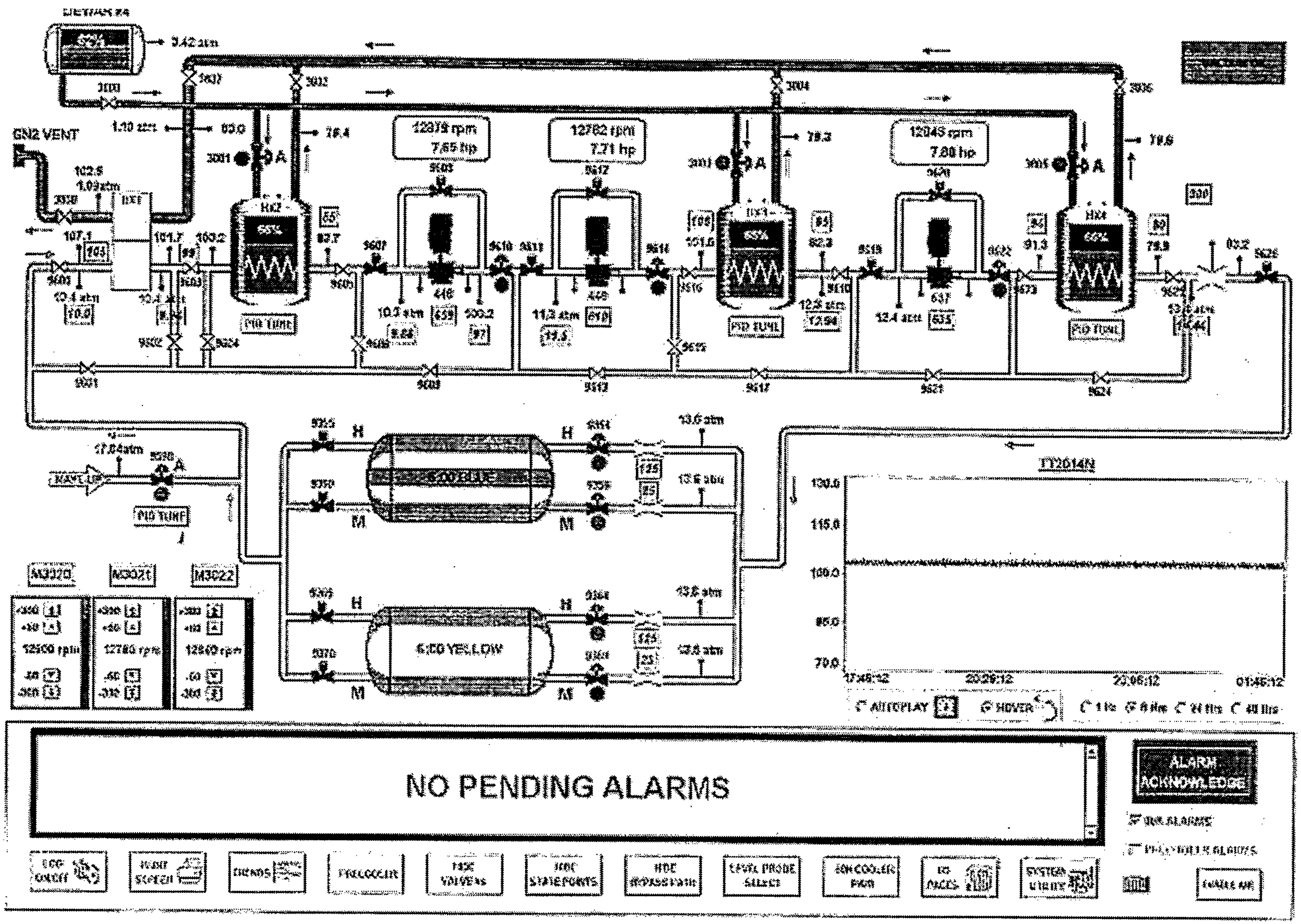


Figure 3: Control Screen for 80K Cooler in Maintenance Mode.

this writing, RHIC is preparing to cool down for the 03/04 experimental physics program. Major modifications to the refrigerator during the shutdown, as well as electrical power consumption limits, have necessitated using of the cool down portion of the Cooler to bring the rings from room temperature to 80K. This will mark the first time this section is used. Based on availability of compressors and manageable Nitrogen usage, each ring is expected to take 10 days to reach 80K. Cool down in this manner has the added benefit of trapping any residual moisture that is left in the magnets in a portion of the cryogenic system that is independent of the main refrigerator and that can be isolated, warmed up and cleaned.

The Cooler's single supply and return lines for the boiling Nitrogen in its heat exchangers lends itself to the possible future addition of a Nitrogen refrigerator. This would eliminate the need for a continuous supply of liquid Nitrogen and would further utilize the sensible heat of the Nitrogen, thus making operations of the Cooler more efficient.

## ACKNOWLEDGMENTS

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